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NOAA'S WEATHER SATELLITES: ECONOMICALLY BENEFICIAL PATHFINDERS

by

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The National Oceanic and Atmospheric Administration's (NOAA) meteorological satellites have made many important contributions to society since their first introduction over 30 years ago. These polar-orbiting and geostationary satellite systems provide weather information as well as other benefits to both the public and private sectors. This thesis examines a number of these economically benefitted areas and quantifies these contributions when possible. Additionally, the concept of weather satellite provided data as a public or a private good is analyzed.The growing private sector application of satellite derived data, or so called value-added service, is surveyed. A few key examples of this field are identified, and the impacts of past, current, and future governmental data dissemination policies are discussed. In conclusion, the role NOAA's environmental satellites will play in the planned global observation of the earth is discussed. By studying these satellite systems in this way, their worldwide benefits to society can be ascertained, both in terms of current economic benefits as well as their important role as a test case for the future of earth remote sensing.

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ECONOMICALLY BENEFICIAL PATHFINDERS

by

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Submitted in partial fulfillment of the requirements for
the degree of

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ABSTRACT

The National Oceanic and Atmospheric Administration's (NOAA) meteorological satellites have made many important contributions to society since their first introduction over 30 years ago. These polar-orbiting and geostationary satellite systems provide weather information as well as other benefits to both the public and private sectors. This thesis examines a number of these economically benefitted areas and quantifies these contributions when possible. Additionally, the concept of weather satellite provided data as a public or a private good is analyzed. The growing private sector application of satellite derived data, or so called value-added service, is surveyed. A few key examples of this field are identified, and the impacts of past, current, and future governmental data dissemination policies are discussed. In conclusion, the role NOAA's environmental satellites will play in the planned global observation of the earth is discussed. By studying these satellite systems in this way, their worldwide benefits to society can be ascertained, both in terms of current economic benefits as well as their important role as a test case for the future of earth remote sensing.

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I. INTRODUCTION

Since 1961, when the first polar-orbiting weather satellite (POES) was launched, this satellite system has been of tremendous benefit to society. When the first geostationary satellites (GOES) were launched in 1966, Americans were treated to their first images from that vantage point 35,788 kilometers out into space. The purpose of this thesis is to provide an overview of the United States weather satellite program from an economic perspective, evaluate various financial considerations, and demonstrate the important role this system has in the future of global remote sensing.

Chapter II of this thesis is an introduction into the current organization of the U.S. meteorological remote sensing system as operated by the NOAA. The POES and GOES satellites will be described and their applications overviewed.

The costs and benefits of the weather satellite system are addressed in Chapter III. Besides pictures on the evening news, what other benefits are derived from data sent down from satellites? In particular, can dollar savings be attributed to the satellites and the data they provide? How much of a benefit to the average American citizen are they? In the event that quantitative benefits are not available, qualitative economic benefits will be discussed. These benefits may go directly to society as a whole or to individuals in the form of research input or as commercial, private sector gains in a more market-oriented sense.

There exists a significant value-added commercial market for weather satellite data. This market consists of those involved in producing the systems to access satellite data, as well as those involved in attaining the data, enhancing it, and providing it to specific market niches. This value-added market will be

discussed in the Chapter IV. A number of firms involved in the value-added sector will be surveyed. Government oversight of the commercial application program will be reviewed, and this oversight will be discussed in terms of possible effects on the future of the program.

The final section, Chapter V, will review the role these systems will play in the future, in particular, their impact on the International Geosphere-Biosphere Program (IGBP). Geosphere is a collective term including the atmosphere, the world ocean, the land surface, the polar regions and the Sun. Biosphere is a collective term for Earth's habitat of living organisms. The IGBP is a multi-dimensional effort to understand the processes, cycles, and interactions concerning these Earth systems on a large, interactive scale. This effort, carried out over an extended period of time of 15 years or more, is expected to lead to enhanced predictive capabilities concerning global change. It also will assist in enabling world leaders to make informed decisions concerning man's influence on the global environment.

The goal of this thesis is to show that, by taking a broad view of economic benefits, by looking at the value-added market as a whole, and by discussing their future role, these systems may be viewed in a different way, not only as "weather" satellites, but as something much more. They can serve the nation, and the world, as "pathfinders" for the future, demonstrating benefits in concrete ways, serving as a test case for data policy, and contributing to the long term study of global interactions. The NOAA polar-orbiting and geostationary satellites are part of a system that is vital to American interests as well as global interests, both in the market place and in their service to society as whole.

II. CURRENT ORGANIZATION AND SYSTEMS

A. NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE

The branch of NOAA that oversees the operation of the environmental satellite program is the National Environmental Satellite, Data, and Information Service (NESDIS) located in Suitland, Maryland. Principal NESDIS elements that acquire, process, archive, analyze, and disseminate data provided by both POES and GOES are:

• The National Climatic Data Center in Asheville, N.C., which deals with global climatological data.

• The National Oceanographic Data Center in Washington D.C., which provides global oceanographic data and services.

• The National Geophysical Data Center in Boulder, Colorado, which collects and disseminates products evolving from solid earth and marine geophysical data collection. This center also coordinates the uses of ionospheric, solar, and other space environment information. (Dropp, 1991)

B. MISSION OBJECTIVES

The key mission objectives of the environmental satellite program focuses on these areas (Hussey, 1985, p.217):

• Regular monitoring of the atmosphere on a regular, global basis, with downlinking of data to worldwide ground stations in view of the satellites.

• Regular sounding of the atmosphere on a regular, global basis to enable that information to be entered into numerical weather prediction models.

• Continuous environmental monitoring of the western hemisphere.

• Collecting and relaying of environmental data from remote platforms such as buoys, ships, automatic stations, aircraft, and balloons.

• Relaying alert and location information of distress signals on a global basis.

• The application of environmental satellite data for the purpose of improving environmental services.

C. TIROS POLAR-ORBITING SATELLITES

The first polar-orbiting weather satellite successfully orbited by the United States was launched on April 1, 1960, from Cape Canaveral, Florida and was designated TIROS-1 (Television Infrared Observation Satellite). This launch ushered in the beginning of global meteorological observations on a timely basis. Since that time, four generations, totaling 33 polar-orbiting satellites have been put into orbit with the four current active satellites designated NOAA-9, 10, 11, and 12. (Polar-orbiters are given letter designators prior to launch and number designators following successful launch, i.e., NOAA-F is NOAA-9, NOAA-G is NOAA-10.) These four satellites are all of the Advanced TIROS-N series first orbited on NOAA-8 in 1983. Since NOAA-9 and 10 (launched in 1984 and 1986 respectively) are well beyond their design life, NOAA-11 and 12 will insure the desired twice daily global coverage.

Launched out of the Western Test Range on Atlas-E expendable launch vehicles, NOAA-11 and 12 have near-polar, sun-synchronous orbits at altitudes of 870 and 833 kilometers respectively, resulting in a period of 102 minutes. In their operational configurations, these two satellites are positioned with a nominal plane separation of 90 degrees. NOAA-11 crosses the equator at the same earth geographical location, northbound, at 2:30 PM. NOAA-12, on

the other hand, crosses the equator, in a southbound direction, at 7:30 AM (Figure 1). Typical swath coverage is as given in Figure 2. (NASA, 1989, p. 4)

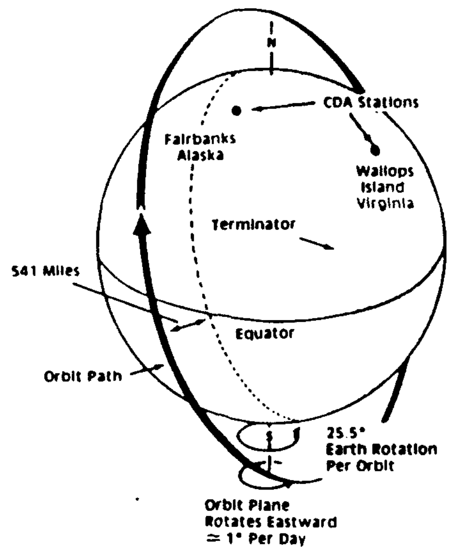

Figure 1: Polar-orbiting Satellites

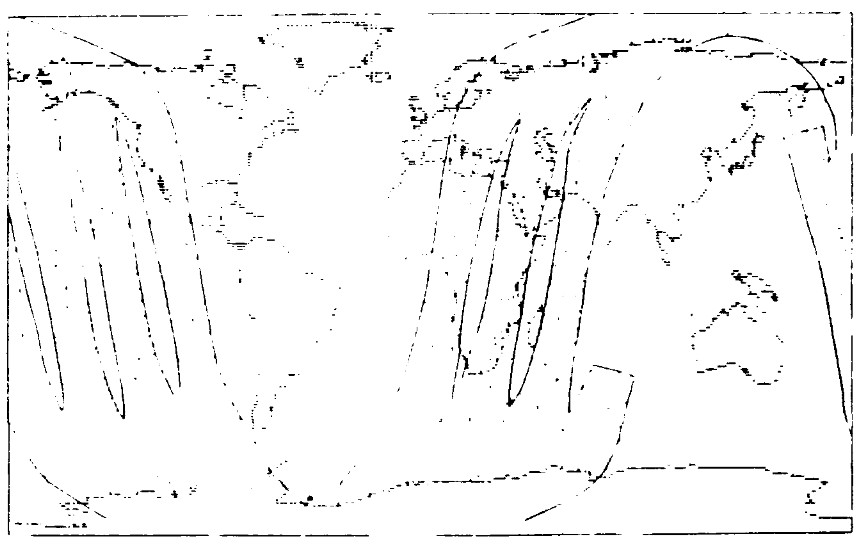

Figure 2: Typical Polar-orbit Swath Coverage

Advanced TIROS-N satellites are three-axis stabilized systems with an on orbit weight of approximately 1030 kg (386 kg for the payload). Full operating power is 475 watts and main body length is 4.2 m, with a diameter of 1.9 m. (Figure 3). (NASA, 1989, pp.9-10)

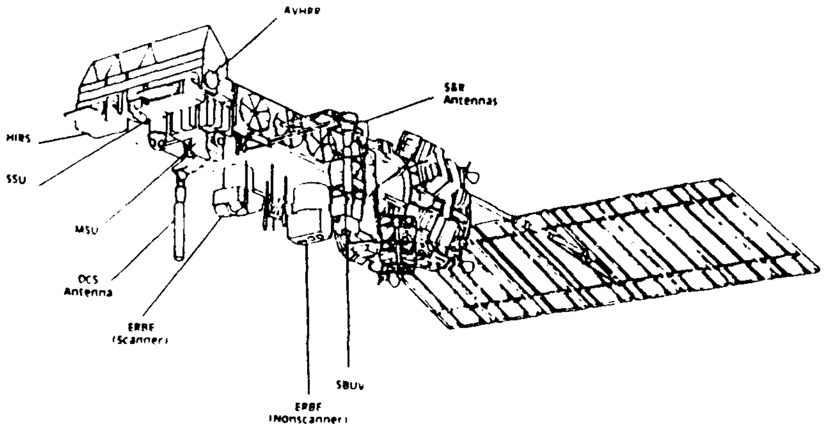

Figure 3: **Advanced TIROS-N Satellite Design**

While specific satellite configurations may differ, generally, the instrument payload for Advanced TIROS-N consists of the following (NASA, 1989, p.12) (Hussey, 1985, p.222):

1. Advanced Very High Resolution Radiometer

The Advanced Very High Resolution Radiometer (AVHRR) is a five-channel scanning radiometer which provides imagery and quantitative radiance data at both 1 and 4 kilometer resolution. It has the capability to record data on board the spacecraft and play it back once per orbit to the NOAA command and data acquisition (CDA) stations located near Fairbanks, Alaska and

Wallops Island, Virginia. This data is subsequently retransmitted to the central processing site at Suitland, Maryland. The AVHRR can also transmit environmental data real-time to users on the ground in view of the satellite. There are well over 1000 automatic picture transmission (APT) receiving stations located in approximately 123 countries worldwide receiving 4 kilometer resolution data. In addition, the high-resolution picture transmission (HRPT) of 1 kilometer resolution is being received by at least 80 HRPT receiving stations in over 50 countries in the world.

AVHRR channels provide for measurement of a variety of data including cloud and snow cover, aerosol content, ice mapping and sea-surface temperature. These instruments are also able to make vegetation and agriculture assessments, land/water distinctions, hot-spot detection (e.g., forest fires, volcanic activity), and soil moisture measurements. In the future, starting with NOAA-K, an addition channel will be added in a time share mode in order to make daytime snow/cloud distinctions.

2. Tiros Operational Vertical Sounder

The Tiros Operational Vertical Sounder (TOVS) is the basic data source for global numerical modeling of the atmosphere. It can also be directly downlinked to ground stations, and consists of three sounding instruments.

The twenty channel High Resolution Infrared Sounder (HIRS) has 17-kilometer resolution and measures vertical temperature profiles up to approximately 65 kilometers, the water vapor content of the atmosphere, and the total ozone content. It is also capable of measuring surface temperatures and clouds.

The three channel Stratospheric Sounding Unit (SSU), with a 147-kilometer resolution, is used to measure temperatures in the stratosphere. The four channel Microwave Sounding Unit (MSU), with a 110-kilometer resolution, assists with atmospheric sounding computations in cloud areas. The ASU will be replaced by the Advanced MSU on NOAA-K and follow-on platforms, providing increased resolution.

3. Solar Backscatter Ultraviolet Spectrometer

The Solar Backscatter Ultraviolet Spectrometer (SBUV), flown only on afternoon polar-orbiters, is able to determine the total and vertical ozone distribution by measuring the backscattered ultraviolet solar energy in the ozone absorption band. It has an accuracy of 1 percent in total ozone measurement and a 5 percent accuracy in the vertical distribution measurements.

4. Space Environment Monitor

The TIROS Space Environment Monitor (SEM) includes three detectors that measure solar proton flux, alpha particle and electron flux density, energy spectrum, and total particulate energy distribution at spacecraft altitude. This data is stripped from the downlinked data stream and forwarded to the Space Environment Services Center (SESC) in Boulder, Colorado. The uses of this data include the monitoring and prediction of solar events (sunspots and flares), prediction of ionospheric conditions affecting radio communications and over-the-horizon radar systems, and predictions of the effects of magnetic storms on electrical power distribution. It is also able to predict radiation levels affecting high altitude aircraft operations as well as manned space activities.

5. ARGOS Data Collection and Platform Location System

The ARGOS Data Collection and Platform Location System (DCS) is a cooperative project among the Centre National D'Etudes Spatiales (CNES, France), the National Aeronautics and Space Administration (NASA), and NOAA. In addition to the space-borne systems on board the POES, it currently includes over 1500 ground user platforms, each equipped with sensors and a platform transmitter terminal. This system enables the precise location of both moving and fixed platforms and the relaying of data from those platforms.

6. Search and Rescue System

The Search and Rescue System (S&R) is a cooperative project among the United States, Canada, France, and the USSR. It enables the detection of distress signals from ships or aircraft on an operational frequency of either 121.5 or 406 MHz and relays this signal to any of the 11 nations which have appropriate ground receiver equipment. Upon computation of a fix (current accuracy approximately 3 kilometers), the position is forwarded to an appropriate rescue agency.

7. Earth Radiation Budget Experiment

The Earth Radiation Budget Experiment (ERBE), flown on NOAA-9 and 10 in conjunction with a dedicated ERBE satellite, helps determine the Earth's heat radiation mechanism. Through this determination, researchers are better able to understand the climatic processes of the Earth and improve climate prediction.

D. GEOSYNCHRONOUS SATELLITES

1. Current GOES System

America's first geosynchronous images came from an experimental NASA series of satellites launched between 1966 and 1974. The current system got its operational beginning with the launch of SMS-A (Synchronous Meteorological Satellite) on May 17, 1974. Since that time, nine geosynchronous satellites have been operated, culminating in the operation of the current satellite, GOES-7. This operational system normally consists of two satellites, the ground data acquisition station and a centralized data distribution system. The two satellites are normally placed over the equator at 75 and 135 degrees West to ensure coverage of the Eastern and Western United States and adjacent ocean areas (Figure 4) (NASA, 1989, p.6).

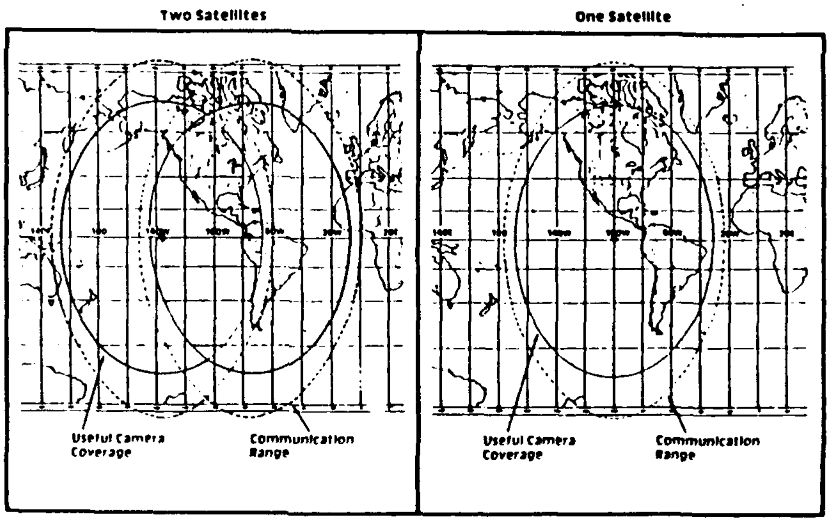

Figure 4: GOES Geographic Coverage

With the loss of GOES-G, during its launch in May of 1986, and the delay of production of the replacement satellites, the system has had to depend on GOES-7 alone. As of August 1st, 1990, coverage assistance has been provided by the European satellite Meteosat-3, through an arrangement with the European Meteorological Satellite Organization (EUMETSAT). Meteosat-3 was shifted to a vantage point above Brazil to assist in filling the coverage gap over the Atlantic ocean. (Lenorovitz, 1991, p.64)

The GOES satellites are launched on Delta expendable launch vehicles and are placed in an orbit of 35,788 kilometers. From this vantage point, they can provide continuous day and night weather observations and monitor large weather events such an hurricanes and other severe storms. In addition, they serve as relay stations for ground based environmental monitoring stations, serve as a relay for ship and aircraft distress signals, and monitor the space environment from their unique vantage point. An additional important use of the GOES system is a relay of low-resolution satellite imagery and meteorological charts to over 160 receiving stations in the Western Hemisphere, more than 100 of them in foreign countries. This weather facsimile (WEFAX) service provides the only satellite imagery available to many countries and is of vital importance to commercial shipping and U.S. military operations. (NASA, 1989, pp. 26-45)

GOES-7, built by Hughes Aircraft Company, is a spin stabilized satellite with a height of 1.5 m and a diameter of 2.1 m. On orbit weight is 503 kg and the peak power requirement is 340 watts (Figure 5). (NASA, 1989, p.28)

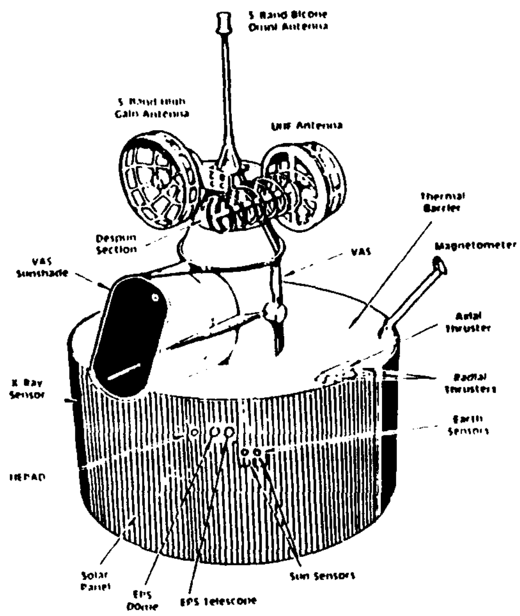

Figure 5: GOES (D, E, F, G, H) Satellite Design

The current GOES-7 satellite has four sensor systems on board (NASA 88, Hussey p.217):

a. Visible-Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS)

The VAS system is the primary instrument of the GOES system and is a multichannel radiometer that produces the traditional visual and infrared imagery of cloud cover and the Earth's surface. Its visible channel resolution is 0.9 kilometers with 12 IR bands with resolutions or 6.9 or 13.8 kilometers. This system has three operational modes. The VISSR mode provides a full disk visible and IR image every half hour. The Multispectral Imaging (MSI) mode uses the two VISSR channels supplemented by two of the remaining eleven IR bands to help depict the amount, distribution, and movement of water vapor at various levels. The third mode is the VAS mode which utilizes all 12 IR channels to calculate the atmospheric temperature

profiles over selected geographic areas. The VAS also enables measurement of wind speed and direction, as well as cloud free sea surface temperatures.

b. Space Environment Monitor (SEM)

The SEM, consisting of three separate sensor systems, is similar to the polar-orbiting SEM. The geostationary SEM measures the Earth's magnetic field, the flow and emission of X-rays, and the concentration of particles emitted from the Sun. One additional use is the prediction and monitoring of the effects of solar activity on the Earth's magnetic field, variations in polar auroral belts, and the intensity of near-Earth radiation belts. This data stream is processed at the SESC in Colorado as well.

c. Data Collection System (DCS)

The GOES DCS, while similar to the polar-orbiting DCS, can not geolocate the transmitting platforms. It can, however, relay environmental data in near real-time from the more than 4800 data collection platforms (DCPs) it services. This system also supports 19 direct readout stations equipped to receive the DCP messages directly from the spacecraft relay. This near instantaneous source of environmental data is very useful in applications such as river level and flood monitoring, tornado warning, and forest fire index measurements.

d. Search and Rescue

Part of the same system as on the POES, the geostationary S&R system was first flown experimentally on GOES 7. This system will enable continuous monitoring for distress signals in view of the GOES satellites. While the polar system will still normally be required for geolocation information, this system will enable alert times to be reduced and rescue efforts to be more

efficient. An advanced system enables position information to be relayed via the satellite. It requires a position interface system tied into the new Emergency Position-Indicating Radio Beacons (EPIRBs). The S&R system is expected to fly on the follow-on satellites as well.

2. Future GOES System

The follow-on GOES systems, called GOES-Next and designated GOES-I,J,K,L and M, are being produced by Loral Space Systems (formally Ford Aerospace). Subcontractor production difficulties have caused the launch of GOES-I to be postponed to the fall of 1992. This satellite will be a three axis stabilized system with an on-orbit weight of 2038 kg, four times that of GOES-7. GOES-Next main structure is a cube approximately 2.5 m on a side, and will have a peak power requirement of 850 watts (Figure 6). (NASA, 1989, p.38)

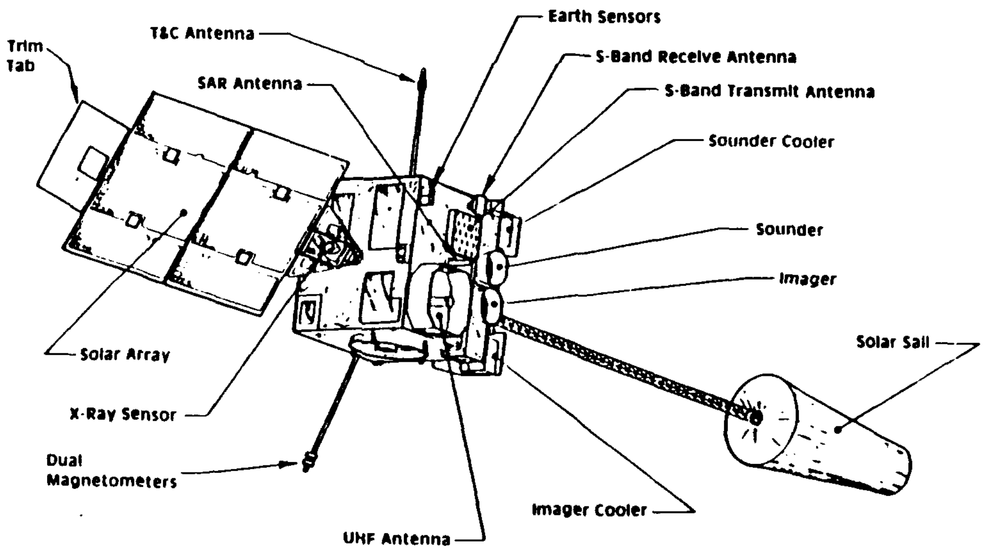

Figure 6: GOES (I, J, K, L, M) Satellite Design

Increased capabilities of GOES-Next are in the imaging, sounding, space environment monitor, and WEFAX systems. Imaging will be able to take place independent of sounding (the two could not take place simultaneously on GOES-7), the number of channels will increase to 5 and IR resolution will improve to 4 and 8 kilometers. In addition, the improved system will be able to selectively scan sub-areas instead of having to be dependent on the horizon-to-horizon East/West strip method of GOES-7. A full Earth disk can be imaged in 30 minutes (as before), a 3000 by 3000 kilometer section in 3 minutes, and a 1000 by 500 kilometer section in 20 seconds. Sounding operations will also be independent, with an increased number of channels (19) and resolution of 8 kilometers for all channels. The improved SEM will include a high energy proton and alpha detector. The WEFAX system, limited on GOES-7 to transmission between images and soundings, will have an independent transmission path on GOES-Next. All other systems will remain essentially unchanged. (NASA, 1989, p.25)

III. COSTS AND BENEFITS

A. SYSTEM COSTS

Prior to review of the benefits of NOAA's meteorological weather satellite program, the costs associated with this program should be studied. As will be seen, benefits of this program reach far beyond the borders of the United States, but for clarity's sake, only the direct costs to the U.S. will be shown. From the largest perspective, the budget associated with the weather satellites is miniscule. The overall U.S. government outlay expected for 1992 is $1,445.9 billion. By comparison, the total obligation for <u>all</u> of NOAA in 1992 is expected to approach just $2 billion. This equates to just .14% of the federal budget. (1992 Budget, 1991, p.1)

On a smaller scale, the NOAA budget itself can be divided. NESDIS, as addressed before, is responsible for the operation of the satellite system and the dissemination of the derived information to the public, commerce, industry, agriculture, scientists, and other government agencies. NESDIS also is fully responsible for the total costs associated with the satellites, and reimburses NASA, who actually procures the satellites. A comparison of the overall NESDIS budget as part of NOAA is exemplified in Figure 7. (U.S. Office of Management and Budget, 1991, p.4-458) While NESDIS is responsible for the weather satellites overall, the benefits derived from them most certainly are assisted by all divisions in NOAA. These other divisions that utilize the remainder of the budget, in addition to basic program management, are the National Ocean Service (NOS), the National Marine Fisheries Service

(NMFS), and the National Weather Service (NWS). The oceanic and atmospheric programs carried out by these other Services help make the most of the country's environmental satellite system.

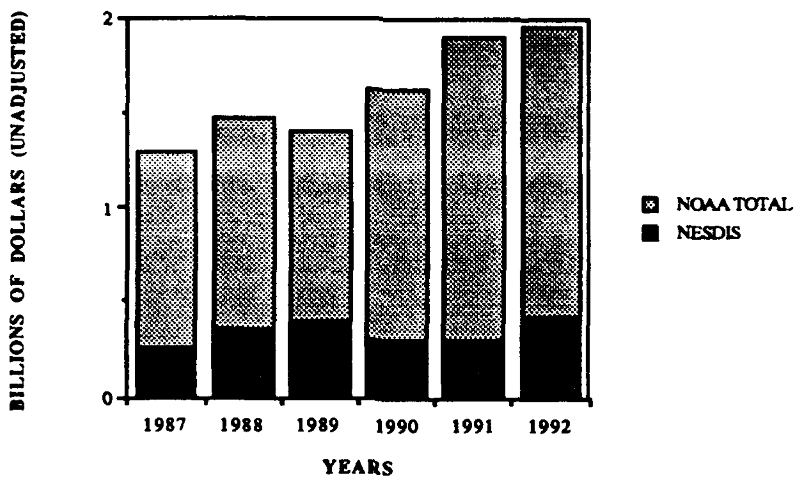

Figure 7: Total Budget Obligations of NOAA vs NESDIS

To establish another environmental satellite benchmark with which to compare the benefits against, the actual cost of the satellites themselves can be pulled out of the overall NOAA budget. In this case, both the future POES and GOES systems will be covered.

NOAA-K, L, and M, scheduled to be launched in 1994, 1996, and 1997 respectively, have an estimated cost of $140 million each. Launch costs for this group will be approximately $43 million. Since the NOAA POES technology is mature, cost difficulties are not expected. The GOES-Next system, on the other hand, has had its share of cost overuns and schedule delays, mainly due to an attempt to increase its capabilities with advanced unproven technologies. The GOES-Next program is now expected to cost $1.1 billion total, with launch

costs for the 5 satellite program to cost $506 million for all launches. (Greaves, 1991)

These costs may seem high to the average citizen, however, as with any large program, a more focused look brings the costs down to earth. A fairly safe assumption can be made in regards to a continuation of the policy of maintaining both a two satellite POES system and a two satellite GOES system. Expecting each satellites life to exceed five years, the cost of both programs development and launch to each citizen in the U.S. would be approximately $1.75 annually. Additionally, as seen before, the NESDIS budget is only a portion of the NOAA budget. If the overall NOAA budget is compared in this way, in order to include all contributing Services in addition to NESDIS, the costs to individual citizens are still small. Assuming an annual NOAA budget of $2 billion, and 250 million citizens in the U.S., the per capita cost for the entire program is $8.

B. OVERVIEW AND ASSUMPTIONS

NOAA's environmental satellites lend support to numerous programs in various ways. This support may take a direct form or an indirect form, that is, satellites may be the only way a program can be successful, or perhaps only a certain percentage of the economic benefit may be attributed to the operation of the system. Recipients of economic benefits include government agencies (national as well as international), private commercial industry or companies, scientific research teams, or the public as a whole.

Attributing economic benefits to environmental satellites is not an exact science. In fact, placing a dollar value on the benefit of the operation of these satellites is very difficult at best and often impossible. The examples that follow

will demonstrate, at the very least, weather satellite's immense variety of areas of influence. Some of these examples can be quantified while others can only be qualified. If the benefits are not directly associated with weather satellites, than the role satellites play, and the degree to which they contribute to costs savings will be identified. A number of the studies reviewed were carried out a number of years ago, presumably when environmental satellites were still proving their worth. The benefits of the studies referred to may be brought forward to the present day or may be addressed in their original time frame. It is beyond the scope of this thesis to individually validate each study. As scientific knowledge advances, contributions of different disciplines change. While remote sensing has made many advances over the years, so have many other fields that have direct influence on the examples to follow. These relative growth rates, and the contributions that come from them as pertains to the studies referenced, are not discussed here. For illustrative purposes, some simplifying assumptions will be made concerning changes in areas such as market growth and associated costs as well. In this complicated arena of cost/benefit analysis, these assumptions will serve to bring the study more into focus than is otherwise possible. The areas covered will demonstrate the scope of economic contributions of environmental satellites in both direct and indirect ways.

Some of these examples that follow could not be possible without the presence of orbiting or geostationary satellites. The goal is to see what areas of society are influenced, to what degree, and to see if any relative economic benefit can be measured from that influence.

C. LARGE SCALE WEATHER FORECASTING

The United States weather satellites contribute to the World Weather Watch. This global system, coordinated by the World Meteorological Organization, provides for the observation, communication, and processing of weather data. All nations of the world are served by this organization.

Knowledge of global temperature and humidity structure, all provided by the TIROS vertical sounding system, are essential for accurate weather prediction. These measurements are inputs to medium and long range weather forecasting. Prior to the advent of the POES, only 20% of the global atmosphere could be measured, either by radiosondes, or ship, airborne, or ground observation. With the launch of TIROS-N in 1978, 100% global coverage was attained and weather ships and dedicated routine weather reconnaissance were subsequently discontinued. The most significant weather improvements were in the extended 3-5 day forecast arena. The improvement in 3-5 day forecasts increased more than 150% with the basic two satellite system in place. The GOES system provides more accurate short term forecasts as well as regional storm warning. (RCA, 1982, pp. 3-10)

Putting the exact economic value of weather satellites in large-scale weather forecasting is a task that is very difficult without inordinate expenditures of time and money. Improvements in forecasting over the years are due to many factors, including both the understanding of the science itself and technological advances. Studies do however indicate that satellite inputs have had a significant effect on these analyses and forecasts. 18-30 hour forecasts of temperature and precipitation today are as accurate as 6-18 hour forecasts in the 1970's. Similarly, 4-5 day forecasts of today match the 2-3 day

forecast reliabilities of more than a decade ago. John Hussey, of NESDIS, in a report written in the mid 1980's stated that "the value of satellite acquired observations to global-scale forecasting is certainly several millions of dollars annually." (Hussey, 1985, p. 251) With increased accuracies in forecasts even since that time, and the growth of global-reaching industries dependent on those forecasts, that statement is probably even more pertinent today than ever.

Environmental satellites are one of the prime sensors involved in the early detection of El Nino conditions. El Ninos, while not totally understood, are normally characterized by an unusual spreading of tropical warm water from the eastern Pacific to the west. This effect can disrupt normal weather patterns over three-quarters of the globe. Areas that normally have sufficient rainfall may be faced with a drought, and those areas accustomed to arid conditions may have record rainfall amounts. The most severe El Nino on record occurred in 1982-83. It triggered flooding and mudslides on the Pacific coastline of the Americas, was blamed for 1500 deaths, and caused between $2 and $8 billion in damage. (Rae-Dupree, 1991, p.5A) With the introduction of environmental satellites that can measure sea surface temperatures, more precise and timely measurements can be made.

D. NATURAL DISASTER WARNING

Environmental satellites are a vital part of the Nation's natural disaster warning system. Satellite data is provided to hurricane and severe storm centers around the nation on an around-the-clock basis. Because satellite input is only part of the scientific advances made in the warning system, it is difficult to put a dollar advantage to them. Natural disasters take a toll not only in property, but in human lives as well, and that cost is impossible to quantify. The

following examples will show, however, the extensive areas of application of satellite data, as well as the scope of damage that can be caused by these natural disasters. In most cases, the damage caused by these disasters is tempered by the capabilities of weather satellites.

1. Hurricane Warning

Satellite observations of hurricanes have all but replaced airborne hurricane reconnaissance. In the early 1960's, the U.S. Air Force operated over 100 aircraft with the sole mission of detecting and tracking hurricanes and tropical storms. The normal first indication of severe weather out at sea was a report from a ship that was right in the midst of it. Today, one squadron of WC-130 hurricane reconnaissance aircraft is in operation and these aircraft cost up to $3000/hour to operate. (Carter, 1991) With an average mission of over 10 hours, the costs can be significant during one hurricane season. In addition, the introduction of satellites have made the search patterns of these aircraft more efficient. In an average year, the savings brought about by satellite utilization amount to as much as $1,800,000. (Hussey, 1985, p.243)

Accuracy of landfall prediction also has a cost benefit side. A 1975 Technical Memorandum issued by NOAA in 1975 studied the economic potential in decreasing the size of hurricane warning areas. Given an average 300 nautical mile warning area ahead of the storm, protection costs amount to over $50 million dollars. Since most hurricanes have typical damage swaths of 100 n. mi., there exists a 200 n. mi. overwarning area. By decreasing this area through the use of more accurate satellite predictions, expensive protection measures can be kept to a minimum. With an average of two hurricanes moving inland on the continental U.S. annually, a conservative 5% reduction in

the warning area could save as much as $5 million annually. (U.S. Congress, Hurricane Weather Reconnaissance, 1989, p.13)

The magnitude of hurricane destruction is illustrated in Table 1 (NOAA Technical Memorandum 31, 1990, p.7) where the 10 most costly hurricanes of the century are illustrated. This table is important because it demonstrates the magnitude of U.S. infrastructure affected by hurricanes. Any contribution by NOAA's satellites toward protecting this infrastructure will certainly have an enormous economic impact.

TABLE 1: COSTLIEST U.S. HURRICANES, 1900-1989 (ADJUSTED TO 1989 DOLLARS IN BILLIONS)

Hurricane	Year	Damage
Hugo (SC)	1989	7.0
Betsy (FL/LA)	1965	6.3
Agnes (NE U.S.)	1972	6.3
Camille (MS/AL)	1969	5.1
Diane (NE U.S.)	1955	4.1
New England	1938	3.5
Frederic (AL/MS)	1979	3.4
Alicia (N TX)	1983	2.3
Carol (NE U.S.)	1954	1.9
Carla (TX)	1961	1.8

Of particular note when addressing the effectiveness of tracking hurricanes is the reduction in the numbers of deaths with the introduction of satellites. As more Americans move to the coast, and property damages due to hurricanes significantly increase, deaths have taken a dramatic drop. A

hurricane the size of Hurricane Hugo came ashore in Texas in 1900 and claimed over 6000 lives. By comparison, Hugo came ashore in South Carolina in 1989 and caused almost seven times as much damage as the 1900 incident, and yet claimed just 28 lives. This led Senator Ernest F. Hollings (SC) to state, in a 1990 hearing of the committee on Commerce, Science, and Transportation, "Securing funding for NOAA's satellite programs may be one of the most important services I, and my fellow Members, can help provide, not only to the citizens of South Carolina, but also to the entire nation." (U.S. Congress, NOAA Environmental Satellite Programs, 1990, p.7) Another prime example of the utility of satellites was shown during Hurricane Elena which came ashore in Mississippi, Alabama, and Northwest Florida in 1985. Even though this hurricane forced the evacuation of 1.7 million residents and caused over $1 billion in damage, no lives were lost. (U.S. Congress, NOAA Authorization -- Space, 1987, p.5)

2. Global Tropical Storm Monitoring

Hundreds of tropical cyclones have been tracked by U.S. polar-orbiting satellites. Annually, there average 27 in the Western Pacific, 10 in the Southern Pacific, and 23 in the Indian Ocean. (Hussey, 1985, p.246) These storms, around the globe, cause untold amounts of damage and loss of life. While Satellite Warning Bulletins are transmitted to countries predicted to be affected, many countries dissemination capabilities are limited. Therefore, unlike the United States, many of the populace are not alerted to the danger, and due to less than adequate transportation systems, most could not evacuate quickly enough regardless. It is only hoped that as methods of informing outlying areas

improve, that all citizens of the world can take advantage of the great benefit environmental satellites can provide in this area.

3. Severe Thunderstorm and Tornado Warning.

Since 1975, GOES data has been an important input to the forecasts issued by the National Severe Storm Forecasting Center (NSSFC) in Kansas City, MO. Terry Schaney, a forecaster with the NSSFC, says that two satellite imagery stations are manned 24 hours a day and that the satellites play a key role in the issuance of severe weather and tornado watches by the Center. (Schaney, 1991) While it is very difficult to predict severe storms and tornados, satellite input has helped increase the accuracy of warning areas and thereby has increased the American public's alertness level. In the 1970's, the average annual deaths in the United States attributed to tornados was 100. Through the 1980's, that average had dropped to less than 30, due, for the most part, to improved prediction techniques and increased public awareness and confidence in those predictions. (U.S. Congress, National Weather Service, 1989, p.2) The number of tornados in 1990 set a record with 1132 touching down. While this is the largest number of tornados in any given year, the deaths attributed to them, 54, was still below the annual average since 1953 of 94. (American, 1991, p.1)

4. Flood warning

In 1979, GOES-1 was shifted over to 58 degrees East to participate in the First GARP Global Experiment (FGGE). This position enabled GOES-1 to image the Yangtze and Yellow Rivers of China and produced some interesting outcomes. Through rapid scanning of the clouds above the region, near real-time cloud dissipation could be measured and correlated to the ground truthed rainfall amounts. This analysis, similar to that done in the past, was an example

of the type of information that can be most useful when trying to estimate expected rainfall amount as it relates to flood prediction. (Hung, 1990, pp.19-20) Also, as addressed before, GOES DCP enable the monitoring of many rivers nationwide to alert of flood conditions. Four major floods in 1982 alone caused damage in excess of $2 billion and claimed 150 lives. (Hussey, 1985, p.249)

E. AGRICULTURE

General agriculture is perhaps one of the most widely affected areas in the application of environmental satellite data. Two prime earth resource remote sensing systems are the U.S. Landsat and the French SPOT programs. These systems, with resolutions of 30 and 20 meters respectively are very expensive for a customer to use due in part to this high resolution and also because of their commercial nature. Landsat and SPOT attain this higher resolution by focusing in on relatively small and discreet geographical areas, limiting their overall global viewing capability. The AVHRR sensor on the other hand has the advantage of more frequent coverage of any given geographical location on the earth, given its broader view. AVHRR spectral bands one and two (.580-.60, .725-1.10 μm respectively) offer a capability of monitoring vegetation biomass changes. This instrument can detect soil moisture content, and with its relatively high sensitivity, can discriminate between different global terrain. (Tarabzouni, 1990, p.191) Timeliness is a major difference between dedicated land remote sensing platforms like Landsat, and the weather satellites. Earthsat (Earth Satellite Corporation), of Chevy Chase, MD provides information on the status of major world crops on a regular basis to subscribers, mainly commodities brokers. This service, called "Cropcast", makes use of TIROS

data because it is available almost real time, whereas Landsat data may take up to a month to attain. (Jaques, 1986, p.77)

The benefit to agriculture comes in two areas, direct application of measurements of crop characteristics (as is used in Cropcast), and increased accuracy of weather forecasts stemming from the use of satellites and the subsequent increase in farm productivity.

In 1973, the Space Science and Engineering Center of the University of Wisconsin published a study of the vegetable processing industries of Wisconsin and Minnesota. This study dealt with the impact on the agriculture industry of improved 12 hour forecasts, based on weather prediction stemming from satellite observations less than one hour old. This survey covered the 20 most valuable crops grown in the U.S. When taken on a national level, these crops represent 92% of the total U.S. agriculture crop value, $26 billion. This study showed that by improving the 3-5 day weather forecast (a forecast of great importance for farming), up to $74,000,000 could be saved annually. (Hussey, 1985, pp.228-229) The value of all crops grown in the U.S. in 1990 totaled $67.4 billion (U.S. Department of Agriculture, 1990, p.5). Extending the benefits derived from the Wisconsin study to the present, improved weather predictions for crop growers and processors could amount to as much as $191 million in that region alone.

Data from a 1982 RCA publication show total savings in the western region of the U.S. around that time to be about $400 million annually. Examples of these savings (unadjusted for inflation) due to improved forecasting include:

• General Resource Management -- water removal from ripe cherries using helicopters ($124 M/yr)

• Planting -- planting impact in State of Washington ($70 M/yr)

• Irrigation -- frost protection in Arizona ($500 / Acre)

• Weed and Pest Control -- cost to re-spray due to rain wash off ($8-$10 / Acre)

• Harvesting -- Monterey County grape harvest ($79 M/yr bonus)

• Harvesting -- raisin crop drying harvest vs cover ($800 M/yr potential loss)

Total annual weather-related losses in U.S. agriculture were estimated to be $12 billion at that time. It was estimated that through the application of weather forecasts, protectable losses would average $5.4 billion per year. (RCA, 1982, p. 11) Translated to 1990 figures (using an annual increase, including growth and inflation, of approximately $2 billion per year), where total crop values are $67.4 billion, annual weather related-losses could reach almost as high as $17 billion. Protectable losses could approach $7.5 billion annually.

GOES infrared images can provide 30 minute updates on ground temperatures to an accuracy to 1 degree C. By providing this information to Florida citrus growers in the form of "freeze line" warnings, money can be saved by protecting the citrus crop. Daily decisions need to be made by the growers in regards to either firing up expensive smudge pots to protect their crops or putting their crews on standby to do so. In the mid 1980's, the state-wide average cost of frost protection was approximately $830,000 per hour. Stand-by crews cost $315,000 per hour. By having access to improved forecasting, a net hourly savings of $515,000 per hour was demonstrated. In addition, money can be saved by "fine tuning" the protection measures. The average number of "cold" nights affecting the citrus crop is 35-40 per year. It

has been estimated that increased utilization of satellite data can reduce the need for nightly freeze protection measures by one to two hours, providing a savings potential of $770,000 per cold night. The Californian frost-sensitive harvest in the mid 1980's was $3.7 billion. According to advisory committees in that state, the satellite contribution to weather prediction alone, during the same time period, has contributed to savings of between $15 and 40 million annually. (Hussey, 1985, p.231)

F. COMMERCIAL FISHING

The monetary value of all fishes caught in U.S. fishing waters in 1990 was $3.6 billion (Obannon, 1991). This large industry is greatly assisted by the utilization of satellite observations. Environmental satellites are able to measure sea surface temperature fronts and, through a variety of mechanisms, provide this information to the fishing fleets. Certain species of fish, tuna and salmon in particular, are found near these nutrient-rich fronts, tuna at 16-20°C and salmon at 11-13°C. Since 1981, the San Francisco NOAA Satellite Field Services Station (SFSS) has incorporated satellite-derived information into their frontal zone charts.

A faculty member of Humbolt State University in Arcata, California, Mr. Fred Jurick, who has been involved in this area since the 1970's, has correlated catches of tuna and salmon directly to the use of satellite-derived thermal front charts. One salmon troller had an increase of about one third, almost an extra $12,000, of his normal annual catch using these charts. (Hussey, 1985, p. 225) According to Mr. Jurick, in 1975, he and his fellow researchers could not even give the frontal zone charts away. That all changed in 1976, when, during an unproductive trip, the scouters for the Western Tuna Association decided to

give the charts a try. By correlating two boundary areas shown on the charts to known high probability areas (in terms of oceanographic influences and bottom topography), they located a stock of fish that accounted for the three largest catches of the year. That one application of the specialized charts was an instant success, accounting for an amazing 40% of the Association's yearly catch. (Jurick, 1991)

Mr. Bill Perkins is the General Manager of the Western Fishboat Owners Association (WFOA) out of Southern California. This Association accounts for over 300 vessels, 80 of which are high seas (long range) fishing boats. Mr. Perkins has been told by members that utilization of frontal charts can bring in enough fish to make their season in just three runs. The WFOA, accounting for only approximately 4% of the worldwide albacore catch, is not alone in the use of this technology. Mr. Perkins states that the use of frontal zone charts is now standard practice by most fleets worldwide, especially the Japanese and Taiwanese fleets, which contribute the most to the annual global fish catch.

For informative purposes, according to the statistics division of the NMFS, the worldwide total catch of tuna (and related species) in 1990 amounted to an approximate value of $8.8 billion. Salmon (and related species) catches had a value of $3.1 billion worldwide. Use of frontal zone charts is now standard procedure around the world. With the total global catch topping 219 billion pounds in 1990, every technique to improve efficiency, of which satellite applications are a major contributor, has a tremendous impact. (Obannon, 1991)

In addition to catch size, advantages can also come in the form of fuel savings, due to better predictions of the areas for fleet operations. On the west coast of the U.S., assuming 1000 fishing vessels in the fleet, it has been

estimated that a total annual savings of $2,440,000 can be garnered just for that region. That region is responsible for approximately 19% of the total catch in the major U.S. fishing areas of Alaska, California, Maine, Louisiana, and Texas. (Hussey, 1985, p. 227) Michael Laurs, an oceanographer with the Southwest center of the NMFS indicates that fishermen can save up to 40% of their searching time for their catch if they use satellite data (Systems West, Inc., Computer, 1990, p.3).

Satellite benefits are also evident in Alaska. The Alaskan SFSS provides sea surface temperature charts to approximately 200 users. Again, these charts help identify regions of increased fish population: herring (SST 4°C), red salmon (SST 7°C), silver salmon (SST 11-13°C), and pink salmon (SST 11°C). This information helps save time, labor and money. By notifying one herring processing plant of SST and ice conditions, NOAA charts have saved one company an estimated $7000-8000 per day in wages and fuel costs in placement of their floating plants. With up to 10 floating plants operational for the month long season, that amounts to large savings. Crab fishermen also benefit. King crab fishermen lost more than $3 million worth of crab pots due to unexpected ice formation in 1980. These fishermen are now able to save many of their pots by pulling them up before the ice arrives. (Hussey, 1985, p. 227)

East coast fishermen also use this data to their benefit. Swordfish prefer areas of the ocean with a temperature between 13 and 25 degrees C. According to the president of the Swordfishermen's Association, efficiency of their fleet, over 500 boats, has been assisted a great deal. Where it used to take up to 5 days to find the fish, now the charts lead them right to them, and at an

hourly fuel usage of up to 50 gallons, the savings are substantial. (Hussey, 1985, p. 227)

As an interesting side note, studies are currently underway that will apply satellite technology to the reduction in the size of fish catches, particularly in the Pacific. International agreements are being discussed that could place satellite-locatable beacons on board the Taiwanese fishing fleet to assist in the enforcement of U.S. territorial fishing rights. This program emerged over recent concerns involving over-fishing of certain ocean areas.

G. OCEAN TRANSPORTATION

The utilization of ocean currents for more efficient ship transportation was well known even before the birth of the United States. When Benjamin Franklin was serving King George III as Deputy Postmaster General for the American colonies, the lords of the treasury wanted to know why it took mail packets two weeks longer to journey from Falmouth, England to New York than a longer route from London to Rhode Island. This lead Franklin to contact his cousin, a Nantucket sea captain named Timothy Folger, familiar in whaling techniques, who described the current that formulated in the Florida Gulf and flowed up the New England coastline until turning sharply eastward. Whales themselves skirted this Gulf Stream to avoid its effects and whalers themselves soon followed suit. This led to the first scientific study of the Gulf Stream by Franklin in 1775, while enroute from London to Philadelphia. This study of temperature variations in and out of the Stream, along with Captain Folger's knowledge, became the basis for a chart of the Gulf Stream and thereby served as a navigational aid for mariners. (Jet Propulsion Laboratory, 1982, p.1)

There are a number of companies involved in ship routing advisory services, the largest of which is Oceanroutes, headquartered in Sunnyvale, California. In its history, Oceanroutes has provided over 200,000 route recommendations to ocean-going vessels, making extensive use of satellite data, in areas like current measurements and weather prediction. Observers of the industry estimate that the worldwide market for ship routing services, of which Oceanroutes is probably the largest, is $10 million annually. (A study of 25 voyages from the west coast of the USA to Japan have shown average time savings of 20 hours per voyage by utilizing ocean routing services. If this benefit were assumed spread throughout the industry, where there are between 600-800 large vessels enroute each day, the effects would be quite large. (EOSAT/NASA, 1987, p.5)

Ship routing utilizing satellite data was first formally studied in 1975 during a joint NOAA/Exxon Gulf Stream experiment. NOAA, utilizing the satellite derived sea surface temperatures, was able to provide Exxon with the boundaries of the Gulf Stream. This seven month study utilized 11 tankers, 5 of which were to proceed by normal navigational means, that is, randomly encountering the Gulf Stream, and the other 6 were to stay in the Gulf Stream on their northerly transits and avoid the current on their southerly transits. The results of this study showed a savings of 31,500 barrels of fuel oil for an east coast fleet of 15 tankers. At $30 a barrel, the fuel savings would amount to approximately $1 million per year. (Hussey, 1985, pp. 223-224) While increasingly efficient and faster tankers make the current less of a problem, knowledge of it is still important for the majority of vessels afloat.

Similar to the Gulf Stream application, there also exists a current in the Gulf of Mexico called the "loop current". This current, the gradient of which is normally only measurable by satellite in the winter months, has a clockwise flow from the Yucatan Straits, around the Gulf, and out the Straits of Florida. The NOAA Miami Satellite Field Services Station (SFSS) produces a Loop Current Bulletin to aid ships much the same way that the Gulf Stream current is utilized.

These routing services are of particular importance to shipping barge and towing companies, whose ships' speeds relative to the currents are fairly small. One such company, the second largest in the U.S., is the Crowley Towing and Transportation Company of Jacksonville, Florida. They operate approximately 60 vessels in and around the Gulf of Mexico and, by utilizing this satellite information as part of a fuel savings plan, have been able to save $2000 per steaming day per tug. Also, by making use of the Gulf Stream on their route from Cuba northward, their barges are able to increase their speed from 9.5 to 12.0 knots, which over a year's time produces operating costs savings of $120,000 per vessel. (Hussey, 1985, p.224)

When the Trans-Alaskan oil pipeline was near completion, another satellite application demonstrated itself to the shipping industry. Alaskan oil is shipped down to U.S. west coast ports where it is pumped ashore. This oil, while enroute, cools due to the cold Pacific Ocean temperatures, and becomes very hard to pump once alongside the docks in California. Ships had to stay alongside the pier an excess amount of time, waiting for the oil to warm up. Not only were pier fees significant, but the productivity of the the tankers was reduced. By utilizing the same worldwide SST charts used for fishing, the tanker captains

can steer a course through water that is a little warmer to help keep the oil just a little more fluid. It was determined that an average increase in enroute water temperature of only 3°F would save $100,000 in pierside costs per vessel. (Jurick, 1991) The three largest oil companies operating in this area have well over 30 tankers sailing along these routes. (Precise numbers are proprietary) Multiplied by the number of oil tankers operating in similar situations around the world, even more significant monetary benefits would be realized.

H. SEARCH AND RESCUE

The main assistance rendered by satellites in the field of search and rescue happen in two main areas, after-incident weather analysis and rapid location of emergency transponders.

If a pilot is overdue from his preflight plan, the U.S. Air Force Rescue Coordination Center (AFRCC) must attain the pilot's planned route, his qualifications, aircraft capabilities, and weather enroute. By correlating these factors, it can be determined if weather was a factor and if so, the most likely place to begin a search. As an example, if the pre-planned route was closed due to heavy thunderstorms, and an alternate route for that particular aircraft, say a mountain pass, was open, then the search might begin either where the weather would have been first encountered, or along the alternate route. The effectiveness of this practice is demonstrated by its use by the California Civil Air Patrol (CAP) starting in 1974. During a study period of 1975-1977, average SAR mission durations were less than two days, down from a pre-satellite high of more than a week. After the introduction of satellite images to assist in SAR, total CAP flying hours decreased by 32% even though the number of missions actually increased by 14%. (Hussey, 1985, p. 235)

One of the greatest advances in the Search and Rescue arena is the introduction of satellite-borne receivers for locating emergency beacons aboard ships and aircraft in distress. The COSPAS/SARSAT program, a joint effort between the U.S., U.S.S.R., Canada, and France, came into operational use in 1982. Its five main benefits are: increased SAR coverage, increased saving of human lives, saving of property, reduction of required SAR resources, and reduction of risk exposure for SAR teams. According to the AFRCC, as of September 1991, there were 4066 registered emergency locator transmitters (ELTs) aboard aircraft in the continental U.S. At the same time there were over 8000 EPIRBs aboard ships in the waters under Coast Guard control. As the distress signals are received, they are automatically routed to the appropriate agency. The AFRCC will notify the appropriate CAP or Air Force rescue team if the signal is over land and the Coast Guard will notify one of its seven national coordination centers if the signal originates in U.S. coastal or inland waters. (Blakely, 1991) (Bailey, 1991)

As of 31 December 1991, over 1700 saved lives (40% of them U.S. citizens) have been directly attributed to the COSPAS/SARSAT program. The average notification of a need for a rescue, prior to SARSAT, was 36-48 hours. If the emergency transmitter is properly activated, the current average notification is one to two hours. Since the best chances for survival are in the first 24 hours, this time savings is of great importance.

A 1991 survey prepared by the SARSAT Operations Division of NESDIS develops a measurement of the benefit to cost ratio of the program for the U.S. On average, 85 Americans have been saved annually by this system. Assigning an actuarial value to each human life of $1 million, as accepted by OMB,

contributes a total benefit of $85 million. Of the average annual 28 incidents, roughly half have been maritime, with vessels worth about $2 million each accounting for half of those. A conservative estimate of property savings will then be $14 million annually. Assuming one SAR aircraft mission per incidence, and aircraft operating costs of $3500 per hour, search time savings on an annual basis can amount to an average of $4.2 million. Taking these factors together produce an annual benefit to the U.S. of $103.2 million. Costs to the U.S. fall into one of two categories. The space segment responsibility is for integration onto the NOAA satellites. The sensors themselves are provided by the Canadians and French. Total annual integration costs are $1 million per year. Operation and maintenance funding for the U.S. portion of the program amount to approximately $4.3 million per year. With total annual benefits of $103.2 million versus costs of $5.3 million, the benefit to cost ratio is an impressive 19.5 to 1. (NOAA/NESDIS, 1991, pp. 1-4)

I. ANIMAL TRACKING AND OCEANOGRAPHIC RESEARCH

An interesting system on board the POES is the ARGOS system. Coordinated out of France, this program enables geographical location (via Doppler measurements) of earth transmitters, or platform terminal transmitters (PTTs), affixed to moving or stationary objects. In addition, these PTTs can relay a wide variety of data up to the satellite, either for immediate retransmission to a local user terminal (LUT) within the footprint of the satellite, or for storage by the satellite and subsequent relay when over a master ground station. Two uses of this system, animal tracking and oceanographic research, provide numerous economic benefits, and in many cases, enable important

research to occur that otherwise could not be done. As of May 1991, 1701 PTTs were in operation around the globe. (Berger, 1991)

In the field of oceanography, large ocean currents are an important field of study. By placing PTTs on free-floating buoys in areas of interest, measurements of these currents can be gathered from around the world from the comfort of the research lab. Not only can floating PTTs transmit location to the oceanographer, but wind speeds, temperatures, and salinity can also be passed back via the satellite link. Lifetime of the PTT/buoy package is only limited by battery life. With proper control, data measurements can last for a very long time. The savings in manpower, research ship time, and the amount of data attained is clearly of benefit to the scientific community.

PTTs are utilized by animal behavior researchers as well. These PTTs can be as small as 4 inches by 2.25 inches, only half an inch thick, and can weigh as little as 1/3 of a pound. Lifetimes, depending on usage, can extend up to 24 months. Since the POES system has more coverage at the poles than more southern latitudes, these devices are especially useful in the harsh climates of the far north and south. One of the first applications was to tag and track caribou in the Alaskan wilderness. What would normally have taken a great deal of manpower, along with close range VHF tracking equipment, could now be done from back in Fairbanks. To keep scientists and equipment up in those harsh conditions costs a great deal of money. A PTT can cost about $2000 and will probably be lost after a time, but the enormous amount of data gathered is well worth the price to most scientists. (Berger, 1991)

With the assistance of Dr. Bruce Mate, a world-renowned marine scientist, special PTTs have been developed to track the migration and behavior of

whales. One of Dr. Mate's recent successes occurred in 1990 when he was able to successfully track a group of Right whales off the coast of Nova Scotia. The nine PTTs used on these mammals were capable of relaying location, dive times, and depth of dive information. Two of these specially designed transmitters lasted for 42 days. According to Sharon Newkirk, the use of PTTs in the study of marine mammals is of tremendous value when compared to conventional VHF or visual tracking. To charter an ocean capable ship for a month could run upwards of $40,000, not including the cost of the research team themselves. (Christman, 1991) Since whales travel alone at times, to keep track of a large group would require one vessel for each. It is impractical to assume that any research program could afford the ships necessary to gather the amount of data readily available via the ARGOS system. (Newkirk, 1991)

J. ICE MONITORING

The presence of sea ice can have a detrimental effect on northern latitude shipping and exploration industries. NOAA satellites have proven themselves in numerous instances to be economically beneficial. An example of one company's utilization of NOAA satellite data is ARCO Oil Company. In 1979, ARCO was drilling for oil near Alaska with a ship designed for use in the Gulf of Mexico. Because they were monitoring sea ice conditions via NOAA data, they were able to save $45,000 in insurance premiums on this project. In 1983, ARCO was using a similar rig to drill in the Aleutians. Cold temperatures and strong winds moved sea ice toward the rig at a rate of approximately 50 kilometers per day. By monitoring this movement, the rig was able to work up until it was safely towed out of danger. (Hussey, 1985, p.238)

The Canadian Centre for Remote Sensing (CCRS) has provided sea ice reports, produced from NOAA satellite data, that have had benefits as well. In one instance, an oil and gas exploration ship performing seismic operations was re-routed to an ice-free region 180 kilometers away and was able to attain twice the amount of data as usual. This one instance of real time application of satellite data saved the company $250,000. Canadian ice reconnaissance aircraft are also more efficiently scheduled, assisted by satellite data, at an annual savings of 1500 flight hours with a corresponding total savings of $5 million. (Hussey, 1985, p.238)

Another beneficial application, this one occurring in 1975, occurred while construction was taking place on the Trans-Alaska oil pipeline. The extremely harsh summer caused dangerous sea ice, and the supply barges had to be routed around this danger using satellite data analysis. Without this satellite information, and subsequently, without the barges, construction would have been delayed a year with billions of dollars in delayed taxes and lost revenue. (National Research Council, 1985, p.72)

In the Great Lakes region, shipping traffic is dependent on ice-free traffic lanes. Satellite data can provide accurate indications of closed or open routes, thus saving needless closure and the expense that goes with it. It is estimated that $1 million a day is lost for every day the shipping season is shortened. Before the use of satellite data, the shipping lanes of the Great Lakes were closed about two months out of every year. After the introduction of satellite coverage, this time significantly decreased. The harsh winter of 1976-1977 only closed the lanes for one month, and the winter of 1977-1978 saw the lanes operational the entire winter. This increased access could also be partially

attributed to the introduction of airborne side-looking radar, but nonetheless, satellite contributions could benefit this region up to an amount of $30 million annually. (Hussey, 1985, p.239)

K. OIL AND GAS EXPLORATION

The Loop current addressed in the ship routing section is also of importance to the positioning of oil exploration and production equipment. AVHRR data provides eddy forecasts which help oil firms plan their drilling schedules better. (EOSAT/NASA, 1987, p.13) In Norway, the application of AVHRR data analysis is helping to forecast polar lows, which produce strong surface winds and are a threat to oil firms in the region. These forecasts can help reduce the number of casualties or the amount of equipment damaged. (Strom, 1985, p.71)

From an environmental standpoint as well, weather satellites play a role. Not only can satellite analysis identify environmentally sensitive areas prior to exploration and production, but they can fairly easily monitor oil slicks when they do occur and measure their dispersal. The most recent example pertains to the massive oil slick in the Persian Gulf. Mr. Doug Grice, of Terra-Mar Resource Information Services Inc., of Mountain View, CA was able to take all five AVHRR bands, split, enhance, and recombine them into a useful product. The movement of the slick could be easily followed, and with color enhancements, the thickness of the slick could also be ascertained. (Grice, 1991, p.9)

L. AVIATION PLANNING

A study was presented at a 1981 symposium on commercial aviation energy conservation strategies which brought forth the idea of incorporating

satellite data to improve commercial flight planning. By improving forecasts and making flight plans more efficient in this way, estimated fuel savings could approach 2-3%. (Steinberg, 1981, p.3) To give a relative size to this savings percentage, it should be noted that the top four U.S. carriers by size, United, Delta, Northwest, and American, have an annual fuel budget topping $6 billion. If this approach to forecasting, of which timely satellite measurements are a part, does contribute just 2% to annual savings, that amounts to $120 million a year for these four carriers alone. (Goble, 1991)

In the aftermath of a volcanic eruption, the infrared band of the AVHRR sensor is able to track volcanic clouds long after their visible signature has dissipated. With this information, alerts can be given to airline pilots via the FAA to enable avoidance of the clouds and possible engine damage. (D'Aguanno, 1991)

M. FORESTRY

During the 1981 forest fire season, NOAA discovered that the AVHRR system could detect "hot spots" on the ground. Steel plants, oil refineries, and volcanic activity could be sensed from space. When a hot spot was correlated with a forest area, the Forest Service was notified. A number of unreported fires were found this way and search aircraft were directed in. The dollar value of satellite data in prevention of forest fires is difficult if not impossible to measure. (RCA, 1982, p.14) This capability of the AVHRR to measure vegetative cover around the globe, if adopted by the United Nations Food and Agriculture Organization (FAO), will assist in that organization's publication in 1992 of the FAO tropical forest assessment. The bulk of data on global deforestation, a major international concern, has come from Landsat and POES

systems. Eric Rodenburg, Research Director of the World Resources Institute, before a Senate committee, stated that the AVHRR "has taken on a workhorse role in the assessment of forest health, forest extent, and general vegetative cover on the Earth." (U.S. Congress, NOAA Environmental. 1990, p.65)

N. PUBLIC UTILITIES

The Space Environment Monitors, aboard both POES and GOES systems, provide solar activity measurements to the Space Environment Services Center in Boulder, CO. This center provides alerts, forecasts, indices, and reports that pertain to the Earth-space environment to subscribers throughout the world.

Some of the major users of this service are electric utility companies. Geomagnetic storms associated with solar and sunspot activity can produce a quasi-DC current that runs along long power transmission lines and can cause tremendous damage. On the evening of 13 March 1991, the Canadian province of Quebec was thrown into darkness due to a massive geomagnetic storm. Geomagnetic induced current (GIC) caused fluctuations in the Canadian system, damaged numerous transformers, and caused the entire system to collapse within 18 seconds. The cost of this collapse, due to damaged equipment (replacement transformers at the price of several million dollars each) and replacement energy costs ($400,000 per day), was easily several millions of dollars. (Kappenman, 1990, p.27) A recent study estimated the potential cost of a major geomagnetic storm caused blackout in the northeast U.S. could cost between $3 and 6 billion dollars. (U.S. Department of Energy, 1991, p. 3)

The SEMs help predict these types of events. Although these predictions are not as accurate as needed, due to a lack of data and experience in

predicting the solar wind, they still serve an important purpose in our understanding of these geomagnetic storms. As the predictions get better, the economic benefits in this industry alone will be sizable.

Natural gas companies benefit by improved weather reports supported by satellites. These companies are paid by customer usage and for delivery guarantees. If customer use of natural gas, through unexpected temperature drops, exceeds guaranteed delivery, penalties can accrue for the gas company. (RCA, 1982, p.15)

O. WATER RESOURCE MANAGEMENT

Three-to-five day forecasts, improved significantly by satellite data input, are used by many concerns to increase operating efficiency. For instance, the Delaware River Basin Commission, which controls the Chesapeake & Delaware Canal, has shown that a one inch variation in river depth correlates to $500 per barge. If the level of the Canal is accurately known, barges can be filled to capacity and not worry about running aground. By the same token, it the water level is unknown, the barges are not loaded down as much, and their efficiencies drop. Overall barge efficiencies gained through accurate weather forecasts equate to $6-7 million a year for this canal alone.

Accurate river stage forecasting has been seen to yield several $100 million per year in areas associated with city and industry water consumption, irrigation, flood control, and maximizing the output of hydroelectric dams. (RCA, 1992, p.13) Hydroelectric power production depends on accurate 4-8 hour forecasts of temperature in order to prepare their systems for peak loads. A temperature change of 1°C at a customer location will be reflected at the power production site in that 4-8 hour period. Since it takes up to four hours to make

major water flow adjustments or increase thermal power, accurate predictions can be most valuable. In 1973, the Tennessee Valley Authority investigated the effect of increasing satellite temperature observations in order to increase the accuracy of their short-term forecasts. By doing so, they determined that in excess of 1% of operating costs could be saved annually. (Hussey, 1985, p.256) Operating costs of the TVA in 1990 were $2 billion. 1% of that figure equates to $20 million (Balston, 1991).

The same GOES-1 utilization, addressed before, in China in 1979 brought out another use of GOES imagery. The Yangtze River carries plenty of water for the basin it services. The Yellow River on the other hand, is normally short of water and carries an excess amount of silt which causes flooding. Large cumulus clouds were noted to pass over the Yellow River areas, but normally held their rainfall until into the central part of China. GOES cloud data could lead to the modification of these clouds in order to increase the much needed rainfall amount in this region. By doing so, it would bring increased flow to the Yellow River, possibly prevent flooding, and help overcome a problem that has become known as "China's sorrow." (Hung, 1990, p.19)

Snow cover mapping, and forecasts of expected runoffs, can also be considered part of water resource management. For example, 70% of the runoff in the western states is from melting snow. It has been shown that satellite versus aerial snowpack surveys have a cost ratio of 200:1, creating a cost savings in the Sierra Nevada basins alone of more than $1 million per year. In the late 1970's, NASA studied the usefulness of satellites in mapping snow cover. It was found that the use of satellites improved the runoff prediction up to 10%. When satellite derived snow-cover data were applied to irrigation and

hydroenergy uses, an annual savings of $36.5 million was gained at a cost of only $505,000. This yielded a benefit to cost ratio of 72 to 1. (Hussey, 1985, p.241)

IV. FINANCIAL CONSIDERATIONS

A. PUBLIC VERSUS PRIVATE BENEFITS

As demonstrated in the previous chapter, there are a diverse number of benefits that can be attributed to NOAA's weather satellites. These benefits, direct or indirect, can amount to billions of dollars annually, both from a governmental as well as from an industrial standpoint. From the previous examples it can therefore be assumed that the benefit to cost ratio of NOAA's weather satellite program is quite large. On the cost side the weather satellite program has, since its inception, always been paid for by the government. The idea of privatization of the weather satellites was squelched in 1982 by a Congress that believed they were much to vital to the national interest than to sell to the highest bidder. However, as exemplified in the examples before, the benefits side clearly applies not only to the public at large, but to private concerns as well.

The fact that benefits derived from this publicly owned system go to private interests raises some important questions. Should the government continue to wholly subsidize a program which, while certainly having a public benefit, clearly enables private industry to save money? Should these private interests be charged for the benefits they receive from a government built system, and if so, in what amount and how should these charges be levied? Weather information dissemination mechanisms are important factors to consider as well. Most of the public get their weather information from private or semi-public media such as television, radio, and newspapers.

It has generally been considered in the best interest of the nation to have the National Weather Service provide severe weather warnings and common weather forecasts to the public. The main reason for this pertains to overall national well-being. That is, what is good for one part of the nation is good for the nation overall. Public safety and economic impact are two areas that are heavily influenced by weather. Broad-based industries such as agriculture, aviation, ocean shipping, and construction are certainly vital to American interests, but at what point does one differentiate public good from private gain? That is one of the key questions in the public/private goods debate. At what point do we as a nation split public service from industry subsidy? The benefits from the previous chapter amount to billions of dollars. If only the private sector benefits were broken out of that analysis they would still amount to sizable savings. If private interests were charged for data, at what cost would industry continue to use the data supplied by the weather satellites? Should the government try to recover some of their capital outlay for the satellite systems, or should they provide data at reduced cost, hoping for increased utilization by industry and a resultant increased tax base? The immense size of a global weather monitoring program dictates that some governmental resources be applied, but cost reimbursement is being looked at more and more. (National Advisory Committee, 1982, p. 55)

In restricted budgetary times, the U.S. government has had to revisit some of these public versus private goods issues. Decisions made can have major impacts on the safety of the American populace as well as the world's and can certainly influence the contribution of the private sector in the area of weather applications.

B. VALUE-ADDED MARKET

Many of the applications addressed in the preceding chapter fall under the auspices of what is called the value-added market. Value-added applications are generally defined as those that apply to or stem from commercial (or private) enterprises as opposed to the public sector. These services will be focused on in the following sections.

In 1984, the Reagan administration sought to speed the access of weather data to the user and shift more of the responsibility of weather forecasting to the private sector. In response, Congress enacted legislation that approved tax credits for companies involved in software and hardware development that would refine that process. In particular, this legislation affected two main areas of value-added services that will be briefly addressed in this chapter. The first area is that industry which produces equipment such as antennas, satellite tracking systems, and computer interfaces that enable direct downlink reception from the POES and GOES systems. The second area is comprised of those companies that receive satellite data in fairly rough form, either from the satellites directly or from NOAA, and then enhance that data to suit specific customers needs.

Systems West Inc. is an example of the first type of value-added firm. Located in Carmel, CA, they assemble and program total turn-key satellite data receiving packages. These packages consist of the antenna, receiver, advanced processor and color monitors to fully receive, enhance and utilize POES visual and infrared images and SST measurements. An entire package can cost just under $30,000. These systems have found markets worldwide, from fishing fleets to outlying airfields that need timely and affordable weather information.

A similar system, capable of receiving GOES images (as well as other countries geostationary satellite information) is available for under $100,000. Television weather broadcasters find these systems affordable, and are thus able to provide real time enhancements of images of large storm systems and frontal movement. (Ruggles, 1990)

The second type of value-added service is that of forecasting and product enhancement. These are companies that provide to their subscribers forecasts tailored to a specific industry or enhanced products from existing data. For many of these services, weather satellite data provide just a portion, although an important portion, of their inputs. These other inputs can range from Landsat data to ground measurements of weather conditions. While many generic services or products are available directly from NOAA at a fee, they are not of an industry specific enough refinement to be most useful outside the National Weather Service.

Most value-added services have their own satellite data receiving antennas, POES or GOES, thereby avoiding any NOAA data fees. They are able to provide real-time access to the data, and will enhance that data as needed by their customers. Oceanroutes, Inc., located in Sunnyvale, CA is one of these types of firms. With a staff of 250, they provide marine transportation routing, operational forecasting, and a variety of environmental studies helpful to many industries. Another after-market services firm, WSI Corporation, out of Billerica, MA, is one of the nation's largest commercial distribution services for real-time weather forecasts designed for such industries as farming, airport safety, and electric utilities. Earthsat, as addressed before, provides forecasts

to agricultural interests and, in the form of "Cropcast" information, to commodities brokerages.

Sales of these types of firms amounted to over $200 million in 1988. According to the industry trade group, the Association of Private Weather Related Companies, more than 100 companies have sprung up in this industry, providing services to interests worldwide. (Systems West, Inc., What's New, 1990, p.2) As Systems West's motto says, they are truly "bringing affordable weather technology to the world."

C. FINANCING

The U.S. government, as always, is dealing with the issue of how to finance expensive national programs. The weather satellite program is one such program, and may serve as a test for financing arrangements of the future. There are two extremes of how to deal with this issue. The first extreme is one in which the government pays all expenses associated with the system with zero cost to the consumer, private or public. Arguments on behalf of this extreme may focus on the potential strengthening of the national economy. If services are provided at a very low cost, industry will benefit and the resultant increase in the tax base may help offset the increased up-front costs to the government. One concern with this type of funding arrangement might be that while all citizens pay for the satellites, they will probably benefit to varying degrees which might not be fair.

The other extreme for financing the program might consist of a weather satellite system solely funded by private enterprise. Some would say that if the economic benefits to private industry were as high as the prior examples demonstrate, then private industry should be more than capable of supporting

such a system. Or for that matter, a private citizen, through private industry, would pay for whatever benefits apply to their industry. This is a classic case of supply and demand. An argument against this arrangement would be the "infant" industry concern. Due to industries' proprietary concerns, it is difficult to arrive at more than just general benefits as demonstrated before. If the relatively new industry of private weather forecasting and applications is to be self-sufficient, it must have the basis from which to start. If left on its own, the value-added industry may currently not have expanded enough to become self-sustaining.

Between the two extremes are a variety of policy arrangements. Of current note in the U.S. is the recent increase in certain satellite data and weather products user fees. A market analysis, carried out by NOAA, of the industries affected will attempt to determine the effectiveness of this approach (Weiher, 1991, p. 4). In Europe, the weather forecasting industry is evaluating the concept of satellite downlink encryption in order to enable them to charge for access to their weather satellite data (Thiem, 1989, p. 380).

The issue of financing for weather satellites and their derived services is a complicated one. Should an American citizen, via the tax system, help pay for a farmer's increased yield or a fisherman's increased catch? Or if the farmer and fisherman are forced to pay by themselves, will the citizen pay anyway in the form of increased costs at the grocery? Should one of the many States not at risk of hurricane damage pay for a State that is at risk, or will they pay in the long run anyway in the form of increased federal emergency assistance? Intertwined with national weather warnings and forecasting are international agreements, volunteer observers, a vast mostly non-government dissemination

system, and a highly competitive global economy. As goverment budgets decrease, it will continue to be a challenge to ensure fair and appropriate data dissemination policies are enacted to take advantage of such a valuable system.

D. LEGISLATION BACKGROUND AND DATA POLICY

As noted before, in the early 1980's Congress strictly prohibited the commercialization of NOAA's POES and GOES systems. Since that time a main focus of the affected industries and government agencies has been the weather satellite data dissemination policies. Satellite data makes important contributions in three areas: to the international weather watch system, to U.S. government agencies and programs, and to the private sector. In order to participate in international data sharing arrangements, NOAA has not required data user fees of other international participants. NOAA also continues to provide its services to other government agencies, research universities, and not-for-profit institutions at no more than cost of access and distribution. The third area relating to commercial sector data dissemination policies, however, has been the subject of some recent changes.

Prior to 1988, OMB policy required that data collected for an agency's primary mission (in NOAA's case, public weather services and warnings) be made available to any users for just the incremental cost of making that data available. In 1988, Congress passed legislation that created a two-tiered pricing policy concerning NOAA's archived data. This policy would still provide data on a marginal cost basis to agencies, universities, and international organizations with which NOAA had exchange agreements. The commercial sector, however, would be charged a "fair market value" as determined by NOAA. The money collected from the commercial sector by these fees would be

returned directly back to the budgets of the NOAA Data Centers. (Dropp, 1991) (Shaffer, 1991)

This progression toward a commercial data dissemination policy based on "fair market value" has been further hastened by the agreements reached in conference between the U.S. Executive and Legislative branches in late 1990. Part of the 1991 Budget Act was an agreement, under a user fee provision, to allow agencies like NOAA to charge commercial user fees not only for archived data but for certain other types of real-time data as well. The NOAA data affected was a mixed bag of forecast products and certain satellite specific products. The National Ocean Center would raise its fees on various charts, photographs, and tidal information products. The National Weather Service would raise prices on its so called "Family of Services" such as digital facsimile, numerical products information, and other near real-time services. NESDIS would increase its charges on GOES Tap, a service that allows users all around the nation to tie into the GOES data stream. Overall, fees which normally were provided to commercial users at marginal costs were raised well over 300%. Revenues from the sale of these products would not go back to NOAA this time but would go directly into the U.S. Treasury to help reduce the national deficit. A revenue cap of $8 million over five years was placed on this provision by the House. This user fee increase does not affect international users, nor does it impact on research and other non-profit organizations. Companies can still purchase equipment to intercept the NOAA satellites' downlinks directly. (U.S. Department of Commerce, 1991) (U.S. Congress, Congressional Record, 1990)

E. POSSIBLE EFFECTS OF USER FEES AND OTHER POLICY CONSIDERATIONS

Increased user fees, to the extent foreseen, will not bring to an end the benefits seen in the previous chapter. Public safety and government provided forecasts will not be affected, and the satellite downlink can still be received by those that have the proper equipment. As previously defined by Congress, there are certain areas of the nation's infrastructure that are important in terms of the national interest. Among these are agriculture, marine forecasting, and aviation safety. For example, in 1890 Congress legislated agricultural weather as a Federal function and this is not likely to change. (National Advisory, p.54) However, as the national leaders and Federal agencies develop future policies concerning data dissemination, there are some important considerations to keep in the forefront of the decision making process. The future success or failure of the recent increase of user fees, a fee that is applied to the after market or value-added industry, may be just the policy needed to evaluate the validity of the following considerations. NOAA's market survey may provide information about future policies as well.

No one discounts the pressures that are currently felt in regards to controlling spiraling Federal budgets. The user fee provision of the 1991 Budget Act is a response to this pressure. To see the possible effects of this provision on the downstream side, the market itself, NOAA and a sampling of those involved in the value-added industry were contacted. As with any complex issue, every party involved will approach it with certain biases. This is to be expected and the realization of this can further one's understanding of such a multi-sided issue.

NOAA's approach to this issue is as one might expect. Generally speaking, they are more interested in service to the public than worrying about cost recovery. NOAA would most likely prefer to provide satellite derived data to all who need it, including private enterprise, with only a marginal cost basis applied. (Dropp, 1991)

As to be expected as well, is the value-added industry's response to increased user fees. Some see this increase as a major philosophical shift in the way the nation provides data to its citizens. Increased costs of value-added services will most certainly be passed onto the consumer. It is feared that this increased cost will cause the customer to price shop, force smaller private forecasting companies out of business, and through the resultant decrease in competitiveness, lead to mediocrity in the weather forecasting business. This mediocrity could possibly have an adverse effect on the benefits gained by private industries that use this data. (Leavitt, 1991)

Dr. Ken Ruggles, of Systems West, Inc., compares national weather satellites services to the highway system. Because of the immense costs involved, the government pays for the infrastructure and society as a whole benefits. Highway systems however, have their own style of user fees in the form of car and truck registrations, licenses, and associated taxes such as those on gasoline. Perhaps increased satellite data user fees are just an extension of this concept. However, according to Dr. Ruggles, concerns about user fees and any possible restrictions on data dissemination stem from an analysis of the satellite value-added industry itself. He believes that this industry is very cost sensitive, that is, as technological advances bring the price of weather data lower, more and more people can make use of it. He has seen this happen in

the past and expects, with increases in microtechnology and data processing techniques, that the industry may blossom in the future as the costs are lowered further. He sees increased user fees as possibly inhibiting the expansion of the market. (Ruggles, 1991)

Another issue to be considered is that of the size of the bureaucracy that will evolve out of this new Budget Act provision. Will the annual costs to the government to set and enforce cost recovery policies outweigh the revenue that may come in as a result? Overall system inefficiencies may result. (Leavitt, 1991) The planned market impact study may shed some light on this comparison.

There is currently a great deal of discussion taking place concerning data dissemination policies in regards to Landsat and the Earth Observing System programs. While cost recovery methods are not totally discounted, the main focus of these discussions deals with increasing the availability of satellite derived data to the widest possible audience. A parallel could also be drawn with the weather satellite systems. There is a fear that data fees of any type may inhibit industry growth, and curtail any corresponding increase in the national tax base. (Shaffer, 1990, p. 48) In other words, the government may recover more of the POES and GOES system costs by simply providing the data to the users for marginal costs only and collecting the taxes on the enhanced goods and services that result.

The issue of public versus private benefits in the case of NOAA's weather satellites is an involved one. The good of the country, or of the world for that matter, must be weighed against the costs to attain those goods. On the whole, in the form of severe weather warnings and general forecasts, society benefits

through the application of weather satellite technology. Private industries, through a more focused non-governmental value-added industry, benefit as well. In between, and difficult at times to distinguish from the two extremes, are industries that are private when taken at their smallest point but may be considered a public good in terms of national well being. The impact of increased user fees is yet to be seen. Attention should be paid to the market reaction to these recent increases taking into account the considerations outlined above. It is important to analyze this issue from an overall unbiased viewpoint to ensure that the needs of the nation are served and that the maximum potential of the weather satellite system is unleashed.

V. PATHFINDER FOR THE FUTURE

A. GLOBAL CHANGE RESEARCH PROGRAM

As defined before, the International Geosphere-Biosphere Program (IGBP) is a worldwide effort set to begin in 1992 to study the earth on a global scale. The American contribution to this effort is the Global Change Research Program (GCRP). This multi-billion dollar program involves the National Research Council, the Departments of Agriculture, Defense, Commerce, Energy, and Interior, as well as the Environmental Protection Agency and NASA. NASA's contribution to the GCRP is entitled the Earth Observing System (EOS). EOS, through a number of advanced polar orbiters, will provide systematic, continuing observations from low Earth orbit for a minimum of 15 years. The goal is to advance the understanding of the Earth's climate system as a whole, how the system interacts, and understand or predict changes. Funding began for the U.S. GCRP in 1991 with total budget authority of $954 million. 1992 funding is expected to top $1 billion. (U.S. Office of Management and Budget, 1991, Part Two, p. 69) The EOS program is a very significant undertaking. Funding over the life of the program could top $30 billion. (Isbell, 1990, p.3)

B. ROLE OF POES AND GOES

The role that POES and GOES will play in regards to the GCRP and EOS programs is very important. NASA and NOAA have gained valuable experience in coordinating the production, launching, and utilization of the environmental satellite systems. On the whole, it is one of the most successful

long-term space programs around. As part of NESDIS and its three data centers, an extensive archive of climatic, oceanographic, and geophysical data, from satellites and from ground-based in situ measurements, is stored. In the past, as would be expected, NOAA has focused on the operational uses of their satellites. This archived information is of an operational nature. Satellite instrument calibration and long-term data preservation techniques may not be on the level of EOS but restructuring is taking place within NOAA to make it so. Meteorological data attained by the POES and GOES systems will be of great importance in helping to gain a historical perspective on global change. (Booth, 1991) (Shaffer, 1991, p.6)

C. DATA DISSEMINATION

When EOS platforms are operational in the late 1990's, they will transmit the equivalent amount of data as that stored in the Library of Congress <u>each day</u>. To prepare for this, the EOS Data and Information System (EOSDIS) is currently being developed to transform this data into formats usable by researchers around the globe. (Faller, 1990, p.4) NOAA archived data, particularly that provided by POES and GOES systems will serve as a test case for the EOSDIS program. These so called "Pathfinder" data sets will be able to examine the access and distribution mechanisms of EOSDIS in preparation for the onslaught of data expected in the near future. (Booth, 1991) Since the POES and GOES data sets are long-term and voluminous enough they will serve as a superb prototype for the EOSDIS program.

On 2 July 1991, the Office of Science and Technology Policy (OSTP) distributed the policy statements on data management for global change research. The overall theme of these statements was full and open access of

data to all global data researchers. It did not address the access of data to commercial users however. (OSTP, 1991) It is expected that decisions concerning private sector data dissemination fees will be left up to the agency providing the services. (Shaffer, 1991) Just as NOAA's weather satellites will serve as a prototype for the EOSDIS program, they also can serve as a prototype for policies surrounding commercial user fees, if any, associated with the GCRP. The market analysis to be performed by NOAA on the impact of increased user fees could in fact serve as a "pathfinder" in its own right, serving to demonstrate the effects of any possible GCRP/EOS cost recovery programs.

D. INTERNATIONAL RELATIONS AND ORGANIZATIONS

NOAA satellites, in conjunction with other nations weather satellites, have proven extremely effective in contributing to the World Weather Watch segment of the World Meteorological Organization (WMO). This organization has proven that remote sensing can be carried out on an international level and succeed. International ties have been strengthened by the ability of the WMO to cross political boundaries for the benefit of large countries as well as small. On one hand however, worldwide Earth observations, including weather, oceanographic, geophysical and research measurements, currently have a duplicative approach to their operation. The U.S, U.S.S.R., Japan, and the European Space Agency in many cases have similar space and ground segments, data processing facilities and dissemination policies, and incompatible data sets. However, if the cooperation in the organization of the global weather satellite system can be extended to the entire global remote sensing program, many benefits could be realized.

Dr. John McElroy, former NOAA official and current Dean of Engineering at the University of Texas at Austin has presented such a concept for international cooperation in Earth remote sensing. Dr. McElroy envisions an organization along the lines of the International Telecommunications Satellite Organization (INTELSAT) that would combine economies of scope and scale in the observation of weather, oceanographic and geophysical conditions, and global change. This "ENVIROSAT" organization would operate on international and national levels in much the same way. (McElroy, 1991, p.16) The 1990 report to NASA from the Advisory Committee on the Future of the U.S. Space Program has urged a feasibility study be undertaken to examine this suggestion. (Advisory, 1991, p.27) Developed as an international consortium, such an organization could maintain the level of worldwide economic benefits to the public and private sectors and would ensure the widest possible access to satellite data. By combining remote sensing assets of all nations, much could be saved economically and much could be gained technically, scientifically, and politically. The weather sector of the worldwide remote sensing industry, and NOAA satellites in particular since they are the most numerous, can serve as a starting point for further international agreements for the observation of the Earth.

VI. CONCLUSION

In this thesis, NOAA's weather satellites have been studied in terms of economic benefits, data dissemination policies, and their role in the future. An enormous diversity of applications have been found in numerous industries and benefits in the millions of dollars seen. Throughout their history, environmental satellites have certainly proved their worth time and time again, to both the public <u>and</u> private sector. There are many financial considerations to be taken into account when deciding government policies relating to weather satellite remote sensing. There are clearly public and clearly private benefits and costs associated with the operation of NOAA's satellite systems yet the definitions of these two benefits and costs blur together at times. It is this blurring that makes it even that much more important for national leaders to be attuned to the public and private interests and, by doing so, to design national policies that benefit the country as a whole.

In looking forward to the future, NOAA weather satellites will play an important role in data dissemination policies as well as international relations and organizations. As collectors of one of the largest historical archives of global observation data, the polar-orbiting and geostationary weather satellites serve in a unique role as the basis from which global observations can begin. As Dr. McElroy said in regards to the TIROS system, it "is in many respects the technological model for the future of earth observations. Namely, it is multi-instrument, multi-disciplinary, and international in both manufacture and data application." (McElroy, 1986, p.27) Since the GOES system time and time again proves itself in the international large-scale weather forecasting arena the

same could be said for it. NOAA's polar-orbiting and geostationary weather satellites are certainly economically beneficial "pathfinders".

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